Benthic TMDL Development Stressor Analysis Report

Happy Creek

Warren County, Virginia

Submitted by:

Virginia Department of Environmental Quality

Prepared by:

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1.0 Defining the Cause of Impairment

Basis for Impairment
Happy Creek was originally listed as impaired due to water quality violations of the general aquatic life (benthic) standard in the 2008 Virginia Water Quality Assessment 305(b)/303(d) Integrated Report (VADEQ, 2008).

The Virginia Department of Environmental Quality (DEQ) has identified this impairment as Cause Group Code H41R-03-BEN, and delineated the benthic impairment as 8.42 miles on Happy Creek (stream segments VAC-B41R_HPY01A00 and VAC-B41R_HPY02A00). The Happy Creek impaired segment runs from its headwaters downstream to its confluence with the South Fork Shenandoah River.

The DEQ 2012 Fact Sheets for Category 5 Waters (VADEQ, 2012) state that Happy Creek is impaired based on assessments of Virginia Stream Condition Index (VSCI) at biological stations 1BHPY001.29 and 1BHPY002.67. The sources of impairment are listed generically as agriculture and non-point sources.

A biological impairment in Virginia is based on the biological monitoring and assessment of benthic macroinvertebrate inventories and a related habitat evaluation. Biomonitoring allows DEQ to assess the overall ecological condition of streams and rivers by evaluating stream condition with respect to suitability for support of aquatic communities. In Virginia, benthic macroinvertebrate communities are used as indicators of ecological condition and to determine support for the aquatic life designated use. A multimetric macroinvertebrate index, the VSCI, is used to assess the aquatic life use status of wadeable freshwater streams and rivers in non-coastal areas of the state. The VSCI combines a series of biological metrics that are regionally calibrated to an appropriate reference condition (VADEQ, 2006), and combines them into a single value that is sensitive to a wide range of stressors. VSCI values <60 are deemed to be impaired, while those => 60 are considered to be healthy.

The data for the bioassessment in Happy Creek were based on DEQ biological monitoring at the two monitoring sites mentioned previously, together with two sites monitored by the Save Our Streams program (1BHPY-1-SOS and 1BHPY-2-SOS), as shown in Figure 1-1, together with five Friends of the Shenandoah River (FOSR) ambient monitoring sites and a DEQ trend monitoring station (1BHPY003.06).

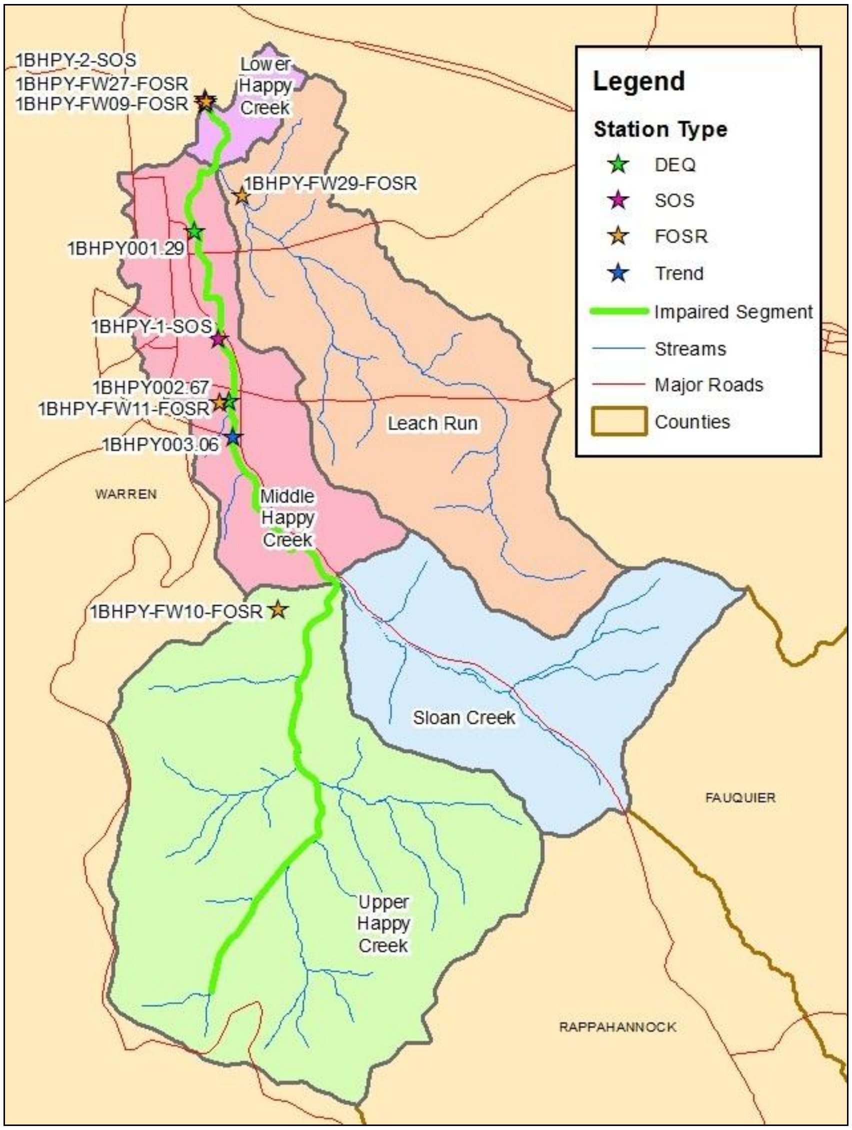

Figure 1-1. DEQ Monitoring Sites in the Happy Creek Watershed

1.1. DEQ Biological Data

The benthic macroinvertebrates data collected in Happy Creek by DEQ are summarized in Table 1-1 through Table 1-4. Table 1-1 and Table 1-2 include the inventory of individual taxa and miscellaneous metrics for each sample, at the downstream and upstream stations, respectively. Table 1-3 and Table 1-4 include the VSCI metric scores and overall ratings. A graph of individual sample VSCI and SOS multi-metric scores for Happy Creek is shown in Figure 1-2. The biological monitoring data was provided by the DEQ Valley Regional Office from the state's Environmental Data Analysis System (EDAS) database.

The dominant species of benthic macroinvertebrates at the downstream Happy Creek site are the pollutant-tolerant chironomidae (A) and Naididae (Table 1-1), while the dominant species at the upstream site (Table 1-2) include a greater mix of pollutant-dominant and pollutant-tolerant species. The primary biological effects at both sites in Happy Creek are the low scores for the sensitive members of the plecoptera and tricoptera families and the scraper functional group (Table 1-3 and Table 1-4).

Table 1-1. Taxa Inventory for Happy Creek (Downstream)

FinalID	Functional Family Group	Tolerance Value	1BHPY001.29								
			05/14/04	10/08/04	05/06/06	10/30/06	04/09/08	10/21/10	03/28/12	10/16/12	05/21/13
Capniidae	Shredder	1						3			
Perlidae	Predator	1	1		2		1	1			1
Stenelmis	Scraper	1								5	
Baetis	Collector	2								2	3
Isonychia	Filterer	2								14	1
Isonychiidae	Filterer	2	3	2		3	1	8			
Nemouridae	Shredder	2	1		1		4				
Taeniopterygidae	Shredder	2						4			
Chimarra	Filterer	3							1	25	
Hydropsychidae	Filterer	3									14
Philopotamidae	Collector	3		1		1	4	14			
Simulium	Filterer	3							8	7	20
Tipulidae	Shredder	3			1		1	1			
Antocha	Collector	4								1	1
Baetidae	Collector	4	34								1
Elmidae	Scraper	4		1	1						
Ephemerellidae	Collector	4					2				
Heptageniidae	Scraper	4	1	14	1		1	11	1		
Psephenidae	Scraper	4	1	2			1	3			
Psephenus	Scraper	4								2	
Cambaridae	Shredder	5		2							
Tricladida	Collector	5								5	1
Ancylidae	Scraper	6			3			2	1	1	
Cheumatopsyche	Filterer	6								12	7
Gammaridae	Collector	6			3						
Simuliidae	Filterer	6	23		3	43		7			
Chironomidae (A)	Collector	6	37	2	63	1	25	23			
Hydropsychidae		6	2	6	1	30	6	20			
Corbiculidae	Filterer	8			3						
Lumbriculidae	Collector	8		9		26		3			
Naididae	Collector	8	1		88		50	4			
Physidae	Scraper	8			3	1				1	
Naididae		9							53		24
Lumbricidae	Collector	10			5			3			
Tubificidae	Collector	10	1	46	2						
Chironomidae (A)		(blank)							40	23	37
VSCI			47	42	32	34	40	63	23	65	35
Scraper/Filter-Collector Ratio			0.02	0.28	0.05	0.01	0.02	0.25	0.20	0.12	0.00
%Filterer-Collector			93.4%	69.8%	92.3%	69.8%	82.8%	58.7%	9.1%	67.3%	43.6%
%Haptobenthos			27.4%	27.9%	6.6%	70.8%	15.2%	53.2%	1.8%	0.9%	13.6%
%Shredders			0.9%	2.3%	1.1%	0.0%	5.1%	7.3%	0.0%	0.0%	0.0%

- Dominant 2 species in each sample.

A number of additional taxa were identified with only 1 organism in all samples.

VSCI: Optimal > 60; suboptimal < 50.

Table 1-2. Taxa Inventory for Happy Creek (Upstream)

FinalID	Functional Family Group	Tolerance Value	1BHPY002.67							
			06/02/08	09/22/08	04/07/10	10/21/10	03/25/11	10/18/11	03/28/12	10/16/12
Epeorus	Scraper	0							2	
Acroneuria	Predator	1							3	
Capniidae	Shredder	1				16				3
Perlidae	Predator	1			1	1				
Amphinemura	Shredder	2							16	
Ephemerella	Collector	2							8	
Isonychia	Filterer	2								30
Isonychiidae	Filterer	2	3	7		5	1	14		
Nemouridae	Shredder	2			39		13			
Taeniopterygidae	Shredder	2				11		1		
Chimarra	Filterer	3							5	
Philopotamidae	Collector	3		16	1	18	1	7		
Simulium	Filterer	3							30	
Tipulidae	Shredder	3	1			1				
Acentrella	Collector	4							13	
Baetidae	Collector	4	40	3	8		1	1		
Elmidae	Scraper	4				2		1		
Ephemerellidae	Collector	4			6		2	2		
Heptageniidae	Scraper	4	3	30	5	13	2	20		
Pleuroceridae	Scraper	4						2		
Psephenidae	Scraper	4	3	5		3		6		
Psephenus	Scraper	4							3	1
Hydracarina (unknown)	Predator	5		2				1		
Ancylidae	Scraper	6		2			2	10		1
Cheumatopsyche	Filterer	6							2	42
Simuliidae	Filterer	6	10	10	44	15	25	2		
Chironomidae (A)	Collector	6	35	2	10	3	59	4		
Hydropsychidae		6	10	34	3	28	3	37		
Naididae	Collector	8	1	2						
Coenagrionidae	Predator	9						2		
Chironomidae (A)		(blank)							23	17
Maccaffertium		(blank)							1	13
Plecoptera (unknown)		(blank)	2							
VSCI			47	65	59	69	39	65	64	46
Scraper/Filter-Collector Ratio			0.07	0.93	0.07	0.44	0.04	1.30	0.08	0.03
%Filterer-Collector			82.6%	35.7%	58.0%	35.0%	80.9%	27.3%	53.6%	67.3%
%Haptobenthos			24.8%	85.2%	51.3%	69.2%	31.8%	79.1%	0.0%	1.8%
%Shredders			0.9%	0.0%	32.8%	23.9%	11.8%	0.9%	14.5%	2.7%

- Dominant 2 species in each sample.

A number of additional taxa were identified with only 1 organism in all samples

VSCI: Optimal > 60; suboptimal < 50.

Table 1-3. Virginia Stream Condition (VSCI) Metric Scores – Happy Creek (Downstream)

StationID	1BHPY001.29							
CollDate	05/14/04	10/08/04	05/06/06	10/30/06	04/09/08	10/21/10	03/28/12	10/16/12
VSCI Metric Scores								
Richness Score	54.5	50.0	72.7	36.4	63.6	77.3	36.4	72.7
EPT Score	63.6	36.4	36.4	27.3	63.6	72.7	18.2	72.7
%Ephem Score	58.5	30.4	0.9	4.6	6.6	29.9	7.4	28.2
%PT-H Score	7.9	3.3	4.7	2.6	25.5	56.7	2.6	68.9
%Scraper Score	3.7	38.3	9.6	1.8	3.9	28.4	3.5	15.9
%Chironomidae Score	65.1	97.7	65.2	99.1	74.7	78.9	63.6	79.1
%2Dom Score	47.7	43.7	24.0	45.0	35.0	87.5	22.3	81.5
%MFBI Score	71.4	33.2	43.1	53.6	50.7	74.3	28.7	97.4
IBI	47	42	32	34	40	63	23	65
VSCI Rating	**Stressed**	**Stressed**	**Severe Stress**	**Severe Stress**	**Severe Stress**	**Good**	**Severe Stress**	**Good**

- Primary biological effects.

Table 1-4. Virginia Stream Condition (VSCI) Metric Scores – Happy Creek (Upstream)

StationID	1BHPY002.67								
CollDate	06/02/08	09/22/08	04/07/10	04/07/10	10/21/10	03/25/11	10/18/11	03/28/12	10/16/12
VSCI Metric Scores									
Richness Score	50.0	59.1	50.0	50.0	59.1	50.0	68.2	68.2	36.4
EPT Score	54.5	54.5	72.7	72.7	63.6	63.6	63.6	81.8	36.4
%Ephem Score	68.8	56.7	31.7	26.0	25.1	8.9	54.9	35.6	65.3
%PT-H Score	7.7	41.5	60.0	99.1	100.0	35.8	20.4	63.8	7.7
%Scraper Score	10.7	64.0	5.6	8.1	29.8	7.0	68.7	8.8	3.5
%Chironomidae Score	67.9	98.3	79.6	91.6	97.4	46.4	96.4	79.1	84.5
%2Dom Score	45.1	64.1	60.3	43.7	87.7	34.2	69.6	74.9	49.9
%MFBI Score	73.3	77.9	77.0	84.5	89.4	68.0	77.5	100.0	83.2
IBI	47	65	55	59	69	39	65	**64**	**46**
VSCI Rating	**Stressed**	**Good**	**Stressed**	**Stressed**	**Good**	**Severe Stress**	**Good**	**Good**	**Stressed**

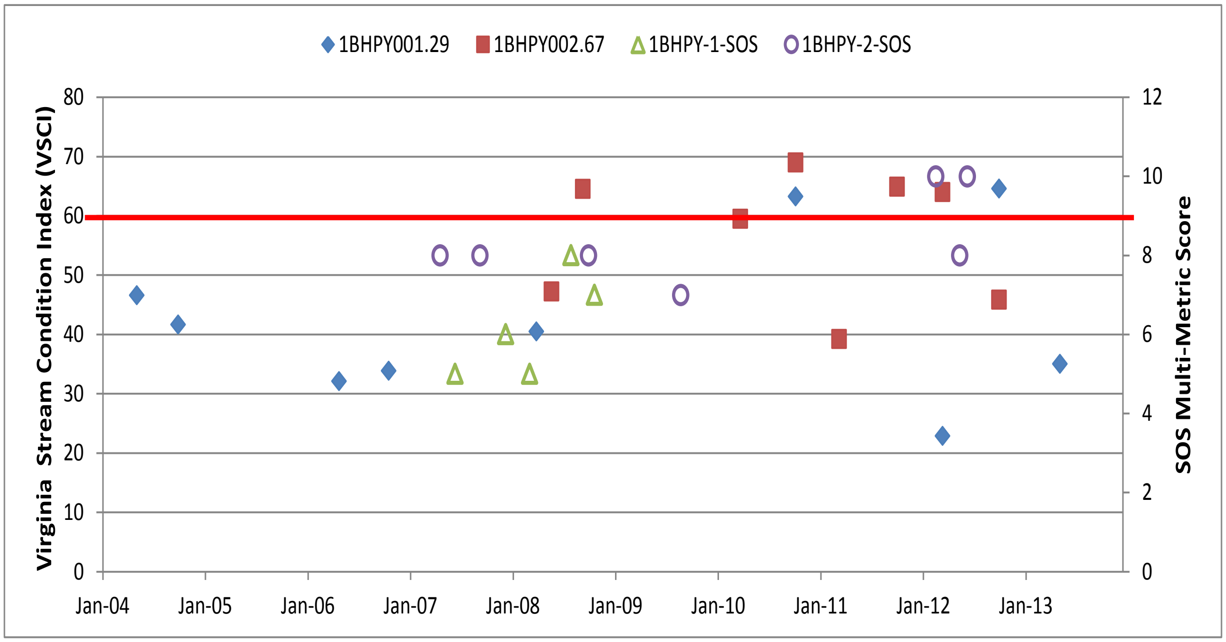

Figure 1-2. VSCI and SOS Multi-Metric Scores for Happy Creek

1.2. DEQ Habitat Data

The habitat assessment data for Happy Creek are shown in Table 1-5 and Table 1-6 for the downstream and upstream stations, respectively. Habitat data collected as part of the biological monitoring were also obtained from DEQ through the EDAS database. The 10-metric total possible score is 200; scores <120 are considered sub-optimal, and those >150 as optimal. The "riparian vegetative zone width" and "channel alteration" metrics have often received "poor" scores at the downstream site, while "riparian vegetative zone width" and "bank stability" were typically poorer at the upstream site. While a slight improvement can be seen in total habitat scores at the downstream site since 2004, scores are still less than optimal, while the majority of the scores at the upstream site have scored in the "optimal" range.

Table 1-5. Habitat Evaluation Summary for Happy Creek (Downstream)

StationID	1BHPY001.29								
CollDate	05/14/04	10/08/04	05/09/06	10/30/06	04/09/08	10/21/10	03/28/12	10/16/12	05/21/13
Channel Alteration	4	11	9	9	12	13	15	6	7
Bank Stability[1]	11	9	12	11	10	11	12	14	15
Vegetative Protection[1]	11	9	13	11	8	10	11	16	16
Embeddedness	15	10	16	14	11	12	17	14	16
Channel Flow Status	18	16	16	18	16	13	18	16	18
Frequency of riffles (or bends)	3	14	11	14	17	15	16	12	13
Riparian Vegetative Zone Width[1]	4	7	4	2	5	4	5	6	4
Sediment Deposition	6	8	16	16	13	15	14	13	14
Epifaunal Substrate / Available Cover	18	11	18	18	14	13	18	16	17
Velocity / Depth Regime	16	16	13	16	15	18	16	14	16
10-Metric Total Habitat Score[2]	**106**	**111**	**128**	**129**	**121**	**124**	**142**	**127**	**136**

- Marginal or Poor habitat metric rating.

[1] Metric is the sum of scores for both the left and right banks.

[2] Total Habitat Score: optimal > 150; suboptimal < 120.

* Substitute metrics used under "Low Gradient" conditions.

Table 1-6. Habitat Evaluation Summary for Happy Creek (Upstream)

StationID	1BHPY002.67							
CollDate	06/02/08	09/22/08	04/07/10	10/21/10	03/25/11	10/18/11	03/28/12	10/16/12
Channel Alteration	16	15	15	15	15	15	15	16
Bank Stability[1]	8	15	16	16	9	8	8	10
Vegetative Protection[1]	18	16	16	16	16	18	17	18
Embeddedness	17	18	17	14	19	14	18	14
Channel Flow Status	18	16	18	11	18	15	17	18
Frequency of riffles (or bends)	17	16	18	17	18	16	16	17
Riparian Vegetative Zone Width[1]	6	6	16	7	8	10	9	10
Sediment Deposition	15	15	15	15	18	14	16	17
Epifaunal Substrate / Available Cover	17	18	17	18	18	18	17	18
Velocity / Depth Regime	18	16	18	18	17	17	18	15
10-Metric Total Habitat Score[2]	**150**	**151**	**166**	**147**	**156**	**145**	**151**	**153**

- Marginal or Poor habitat metric rating.

[1] Metric is the sum of scores for both the left and right banks.

[2] Total Habitat Score: optimal > 150; suboptimal < 120.

* Substitute metrics used under "Low Gradient" conditions.

1.3. Save Our Streams (SOS) Citizen Monitoring Data

Since 2007, the Northern Shenandoah Tributaries chapter of the Izaac Walton League's Save Our Streams program has been monitoring at two locations in Happy Creek shown previously on Figure 1-1, with their time-series of Multi-Metric scores included in Figure 1-2. Specific metrics used as the basis for the multi-metric scores are given in Table 1-7.

Table 1-7. Save Our Streams (SOS) Multi-Metric Metrics and Scores on Happy Creek

Monitoring Site	1BHPY-1-SOS					1BHPY-2-SOS						
Sampling Date	06/23/07	12/21/07	03/15/08	08/10/08	11/02/08	05/01/07	09/20/07	10/12/08	09/06/09	03/04/12	05/28/12	06/24/12
Metric 1 - Percent Mayflies, Stoneflies, and Most Caddisflies	26.76	40.54	25.63	36.02	34.25	51.92	39.78	34.11	22.97	58.20	13.76	33.82
Metric 2 - Percent Common Netspinners	42.25	53.36	38.66	34.60	53.15	36.06	50.93	43.80	31.10	4.69	21.81	19.85
Metric 3 - Percent Lunged Snails	0.47	3.30	1.26	0.00	0.00	0.00	0.00	0.00	0.48	0.00	0.00	0.00
Metric 4 - Percent Beetles	2.35	0.24	1.26	0.47	2.76	0.00	0.00	2.71	2.87	0.00	13.42	13.60
Metric 5 - Percent Tolerant	27.70	4.88	34.45	28.44	8.66	11.54	7.43	18.60	39.71	35.94	33.22	15.07
Metric 6 - Percent Non-Insect	6.10	5.25	5.88	5.21	7.87	0.96	0.74	1.94	2.87	0.00	19.46	14.34
Multi Metric Score	5	6	5	8	7	8	8	8	7	10	8	10
Total Organisms	213	819	238	211	254	208	269	258	209	256	298	272
Sample Season	Summer	Winter	Spring	Summer	Fall	Spring	Fall	Fall	Fall	Winter	Spring	Summer
Ecological Conditions (Acceptable/Unacceptable)	Unacceptable	Unacceptable	Unacceptable	Gray Zone	Unacceptable	Gray Zone	Gray Zone	Gray Zone	Unacceptable	Acceptable	Acceptable	Acceptable

1.4. Focus of the Investigation

The Investigation's purpose

The purpose of the stressor analysis is to look for a stressor that was present prior to the earliest bioassessment sampling in 2004, which caused Happy Creek's initial 2008 listing on the impaired waters list. The stressors may be something that either directly affected the benthic community or indirectly affected its habitat. VSCI ratings for Happy Creek suggest that its benthic community has some general stress throughout the system, but may have increased sources of stress between the upstream and downstream stations. While there are general upward trends in the VSCI scores at both sites, they both have experienced recent scores below 60.

Geographic area under investigation

The Happy Creek watershed is part of the Lower South Fork Shenandoah River basin (USGS HUC 0207005) and comprises part of state hydrologic unit B41 (National Watershed Boundary Dataset PS48). Happy Creek is located in Warren County and includes the town of Front Royal. The Happy Creek watershed is 14,146 acres in size. The main land use category in the watershed is forest, which comprises approximately 66.7% of the watershed, followed by 21.7% in developed land uses, and 11.6% in agricultural land uses. Happy Creek flows north and discharges into South Fork Shenandoah River, which discharges into the Shenandoah River. Shenandoah River is a tributary of the Potomac River Basin, which flows into the Chesapeake Bay.

The Happy Creek watershed is partially located within the Northern Igneous Ridges (66a) sub-division of the Blue Ridge (66) ecoregion and partially within the Northern Limestone/Dolomite Valleys (67a) sub-division of the Ridge and Valley (67) ecoregion. Ecoregion 66a consists of pronounced ridges separated by high gaps and coves. Mountain flanks are steep and well dissected. Crestal elevations tend to rise southward. Ecoregion 67a is a lowland characterized by broad, level to undulating, fertile valleys that are extensively farmed. The Great Valley, the Shenandoah Valley, and the Nittany Valley all occur in Ecoregion 67a. Sinkholes, underground streams, and other karst features have developed on the underlying limestone/dolomite, and as a result, the drainage density is low. Where streams occur, they tend to have gentle gradients, plentiful year around flow, and distinctive fish assemblages (Woods et al., 1999).

The Happy Creek watershed is comprised of a diversity of soils with its dominant soil, Myersville-Catoctin silt loams, only comprising 31.3% of the watershed. The next most abundant soil type is Myersville and Montalto soils at 19.1%, followed by Chester-Manor complex soils and Dyke loam at 6.8% and 6.4%, respectively. The Myersville series consists of deep, well drained soils formed in material weathered from basic crystalline rocks, including greenstone, on nearly level to very steep uplands. Permeability is moderate. Slopes range from 0 to 80 percent. The Montalto series consists of very deep, well drained soils with moderately low to moderately high permeability. They formed in residuum weathered from basic (gabbro) rocks and are typically found in the Northern Piedmont. The Catoctin series consists of moderately deep, well drained soils with moderately rapid permeability. They formed in material weathered primarily from greenstone. They are on nearly level to very steep ridges and side slopes. Mean annual temperature is about 54 degrees F and mean annual precipitation is about 40 inches. Slopes range from 0 to 80 percent (USDA-NRCS, 2012).

Climate data for the Happy Creek watershed was based on meteorological observations made by the Front Royal National Climatic Data Center station (443229) located in the center of the watershed at Front Royal, Virginia approximately 3.35 miles south southeast from the Happy Creek confluence with the South Fork Shenandoah River. Average annual precipitation at this station is 40.9 inches; while the average annual daily temperature is 54.0°F. The highest average daily temperature of 87°F occurs in July while the lowest average daily temperature of 3°F occurs in January, as obtained from climate normal data for the period 1981-2010 (University of Washington, 2014).

Land use categories for the Happy Creek watershed were derived from the 2012 National Agricultural Statistics Service cropland data layer (USDA-NASS, 2012) for Virginia. Broad categories of land use in the watershed are shown in Figure 1-3, while detailed land use is summarized by acreage in Table 1-8.

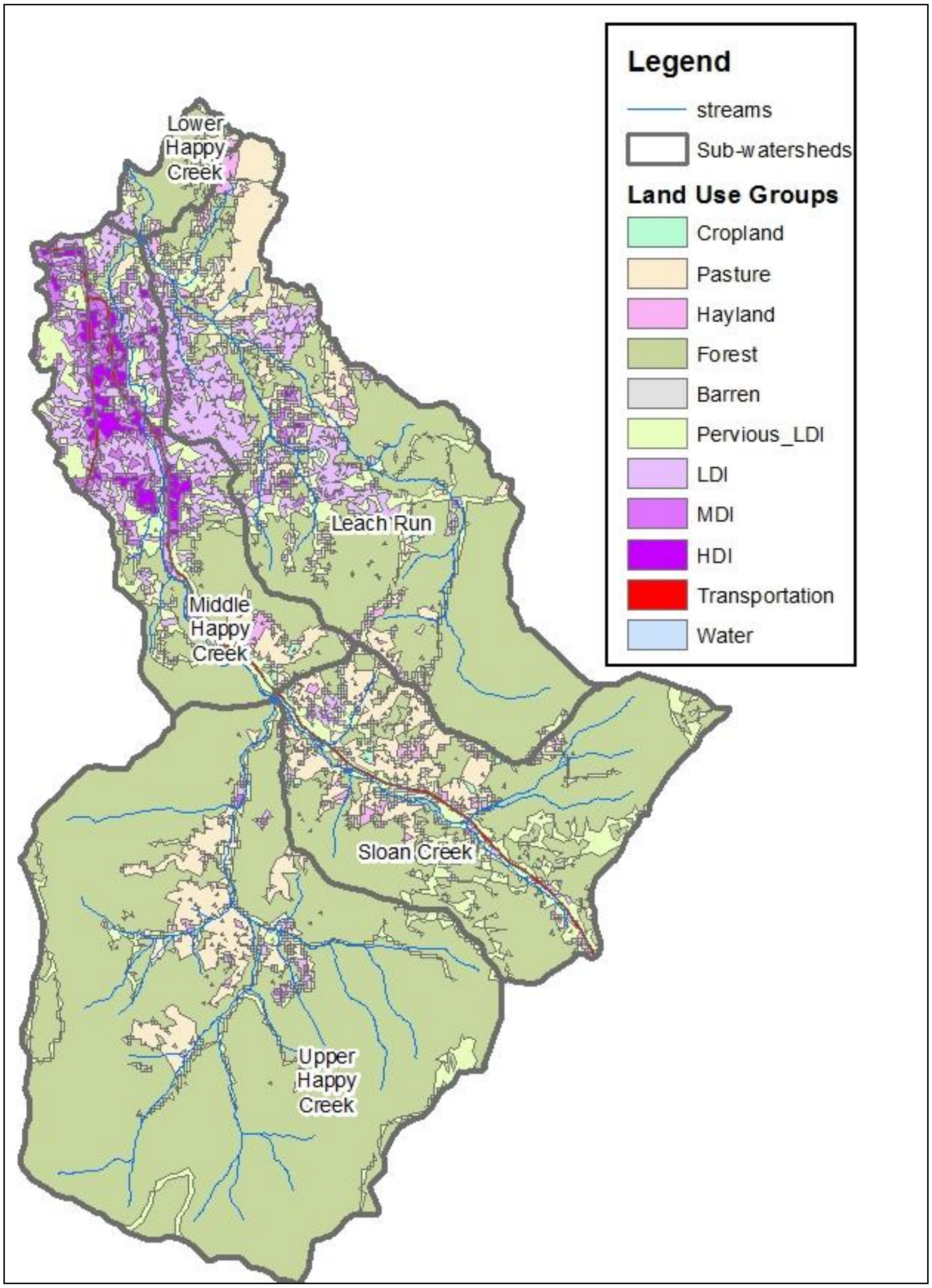

Figure 1-3. Happy Creek: Broad Categories of NASS Land Use

Table 1-8. Happy Creek: Detailed 2012 NASS Land Use Categories

NASS Code	NASS Land Use Class	Area (acres)
1	Corn	11.9
4	Sorghum	0.8
5	Soybeans	1.3
21	Barley	0.4
24	Winter Wheat	3.0
28	Oats	0.1
36	Alfalfa	2.3
37	Other Pasture/Hays	214.1
61	Fallow/Idle Cropland	3.3
62	Pasture/Grass	1,361.9
68	Apples	40.9
111	NLCD - Open Water	10.8
121	NLCD - Developed/Open Space	1,460.1
122	NLCD - Developed/Low Intensity	1,073.8
123	NLCD - Developed/Medium Intensit	328.2
124	NLCD - Developed/High Intensity	144.8
131	NLCD - Barren	0.5
141	NLCD - Deciduous Forest	9,259.0
142	NLCD - Evergreen Forest	137.8
143	NLCD - Mixed Forest	12.0
152	NLCD - Shrubland	0.2
171	NLCD - Grassland Herbaceous	5.9
190	NLCD - Woody Wetlands	1.3
237	Dbl. Crop Barley/Corn	0.4
999	Transportation	70.7
Total Area		**14,145.5**

2.0 Candidate Causes of Impairment

A list of candidate stressors was developed for Happy Creek and evaluated to determine the pollutant(s) responsible for the benthic impairment in the watershed. A potential stressor checklist was used to evaluate known relationships or conditions that may show cause and effect between potential stressors and changes in the benthic community. An outline of available evidence was then summarized as the basis for each potential stressor. Depending on the strength of available evidence, the potential stressors were either "eliminated", considered as "possible" stressors, or recommended as the "most probable" stressor(s). Candidate stressors included:

- ammonia,
- pH,
- temperature,
- metals,
- toxic organic compounds,
- nutrients (dissolved oxygen),
- organic matter,

- streambed sedimentation, and
- ionic strength (total dissolved solids, sulfates, conductivity).

The data used in the evaluation is detailed in Section 3.0, and the evaluation of each candidate stressor is discussed in Section 4.0.

3.0 Data Sources Used in Stressor Identification

In order to investigate and verify the stressor(s) causing the benthic impairment, available bioassessment data, water quality data, special study data, permitted point source data, and ancillary data were examined together with field observations. The extent and content of these data sources are summarized in Table 3-1. Evidence relevant to each candidate cause is summarized in Table 3-2.

Table 3-1. Inventory of Data Used in Happy Creek Stressor Analysis

<table>
<tr><th>Data Type/Location</th><th>Strea m</th><th>Collection Period</th><th>No. Samples</th><th>Description</th></tr>
<tr><td colspan="5">National Agricultural Statistics Service cropland data layer</td></tr>
<tr><td colspan="5">Spatial data as displayed in Figure 1.3.</td></tr>
<tr><td colspan="5">Biological (Benthic) Samples</td></tr>
<tr><td>1BHPY001.29</td><td rowspan="4">Happy Creek</td><td>May-04 to May-13</td><td>9</td><td rowspan="2">DEQ: species counts. Virginia Stream Condition Index (VSCI) scores and ratings (VADEQ, 2006).
Habitat assessment scores.</td></tr>
<tr><td>1BHPY002.67</td><td>Jun-08 to Oct-12</td><td>8</td></tr>
<tr><td>1BHPY-1-SOS</td><td>Jun-07 to Nov-08</td><td>5</td><td rowspan="2">SOS: Save Our Stream metrics and multi-metric index scores.</td></tr>
<tr><td>1BHPY-2-SOS</td><td>May-07 to Jun-12</td><td>7</td></tr>
<tr><td colspan="5">Ambient Water Quality Samples</td></tr>
<tr><td rowspan="2">1BHPY001.29</td><td rowspan="3">Happy Creek</td><td>Aug-01 to May-03</td><td>12</td><td>DEQ: ambient physical and chemical water quality data.</td></tr>
<tr><td>Jan-11 to Nov-12</td><td>11</td><td>DEQ: TN, TP, and E. coli only.</td></tr>
<tr><td>FOSR-FW09</td><td>Jan-07 to May-09</td><td>37</td><td rowspan="5">FOSR: temperature, pH, DO, ammonia-N, nitrate-N, orthophosphate-P, and turbidity.</td></tr>
<tr><td>FOSR-FW10</td><td>Sloan</td><td>Jan-07 to Sep-08</td><td>23</td></tr>
<tr><td>FOSR-FW11</td><td rowspan="2">Happy Creek</td><td>Jan-07 to present</td><td>59</td></tr>
<tr><td>FOSR-FW27</td><td>Jan-07 to Jul-08</td><td>15</td></tr>
<tr><td>FOSR-FW29</td><td>Leach</td><td>Jan-07 to May-09</td><td>28</td></tr>
<tr><td colspan="5">Other Monitoring</td></tr>
<tr><td>1BHPY002.67</td><td rowspan="3">Happy Creek</td><td>2008</td><td>1</td><td>DEQ: Metals in stream sediment, dissolved in water column.</td></tr>
<tr><td>1BHPY001.29</td><td>2012</td><td>1</td><td rowspan="2">DEQ: relative bed stability analysis</td></tr>
<tr><td>1BHPY002.67</td><td>2008, 2012</td><td>2</td></tr>
<tr><td colspan="5">Virginia DEQ Permitted Point Sources</td></tr>
<tr><td colspan="3">Industrial Stormwater Permit</td><td>1</td><td>DEQ: Active permits in the watershed.</td></tr>
<tr><td colspan="3">Pollution Response Preparedness (PReP) Reports</td><td></td><td>DEQ: History of reported spills.</td></tr>
<tr><td colspan="5">VAHWQP Household Drinking Water Analyses</td></tr>
<tr><td>Warren Co.</td><td colspan="2">2012 (n=44)</td><td colspan="2">Summaries of household drinking water quality analyses.</td></tr>
</table>

Table 3-2. Evidence Relevant to each Candidate Cause

Candidate Cause	Relevant Evidence
Ammonia	FOSR ambient data
pH	DEQ and FOSR ambient data, VAHWQP drinking water analyses
Temperature	DEQ and FOSR ambient data, habitat metrics
Metals	DEQ periodic channel bottom sediment and water column analyses, VAHWQP drinking water analyses
Toxic sediment organic compounds	DEQ periodic channel bottom sediment analyses, permits
Nutrients	DEQ and FOSR ambient data, DEQ and SOS species counts, biological metrics, VAHWQP drinking water analyses
Organic Matter	DEQ VSCI metrics, ambient data
Streambed sedimentation	Habitat metrics and total scores, field observations, RBS
Ionic strength	DEQ ambient data

3.1. DEQ Ambient Data

- Ambient bi-monthly monitoring has been performed on the Happy Creek impaired segment at the 1BHPY001.29 ambient station since August 2001.
- Nutrient data in Happy Creek are summarized in Table 3-3 to assist in assessing nutrient influences in these watersheds.

Table 3-3. Nutrient Concentration Averages and Ratios at 1BHPY001.29

Period	TN		NO2+NO3-N		TKN		TP		TN:TP	TKN:TN
	No.	Ave.	No.	Ave.	No.	Ave.	No.	Ave.	Ratio	Ratio
2001 - 2003	0		12	0.47	12	0.23	10	0.042	16.6	0.32
2011 - 2012	12	0.58	0		0		1	0.010	58.4	--

- Plots of monthly ambient water quality monitoring sample data for the ambient monitoring station in Happy Creek are shown in Figure 3-1 through Figure 3-11.
- Where applicable, minimum and/or maximum water quality standards, minimum detention limits (MDL), and sample analysis caps are indicated on the plots. All stream segments within these watersheds are Class IV Mountainous Zones Waters (9VAC25-260-50). The upper portion of Happy Creek from Front Royal's raw water intake to its headwaters, including Sloan Creek is also classified as a Public Water Supply (PWS) (SWCB, 2011).
- Field physical parameters include temperature, pH, and DO. Chemical parameters include: total N (shown on 2 separate graphs for 2001-2003 and 2011-2011); total P (shown on 2 separate graphs for 2001-2003 and 2011-2011); and ammonia (no samples above the minimum detection limit – data not shown). Conductivity, hardness, suspended solids, and chlorophyll were only collected from 2001-2003.

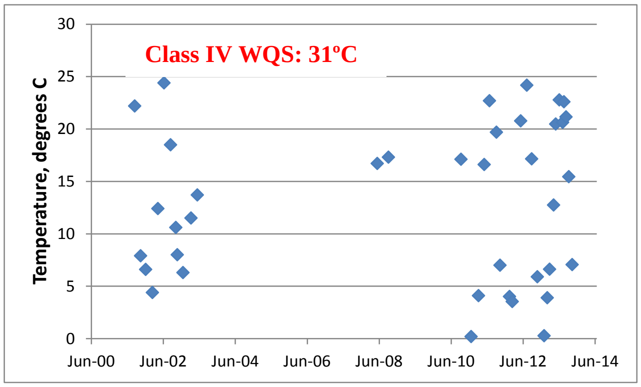

Figure 3-1. Field Temperature

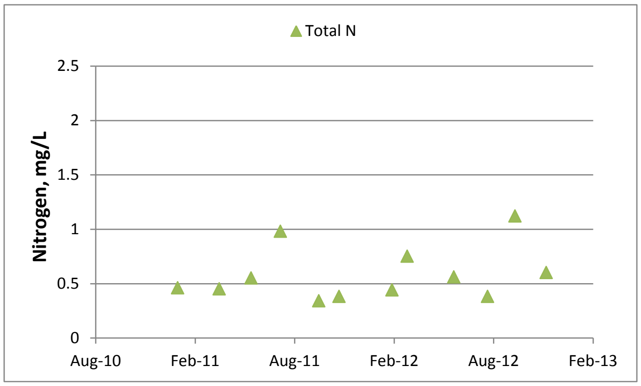

Figure 3-5. Nitrogen 2011-2012

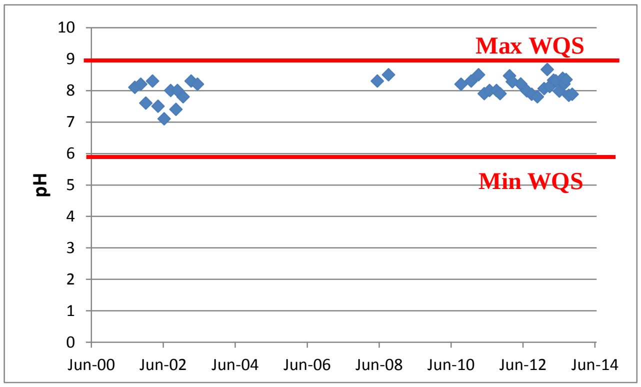

Figure 3-2. Field pH

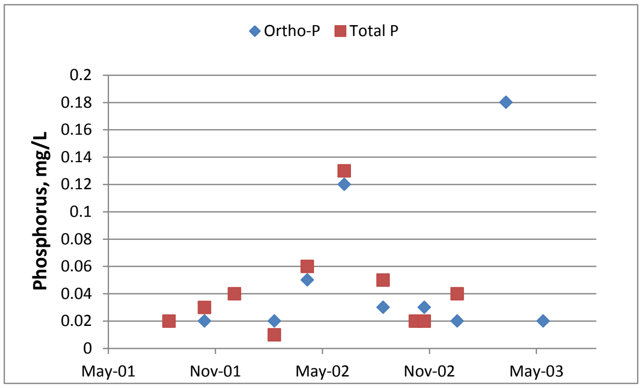

Figure 3-6. Phosphorus 2001-2003

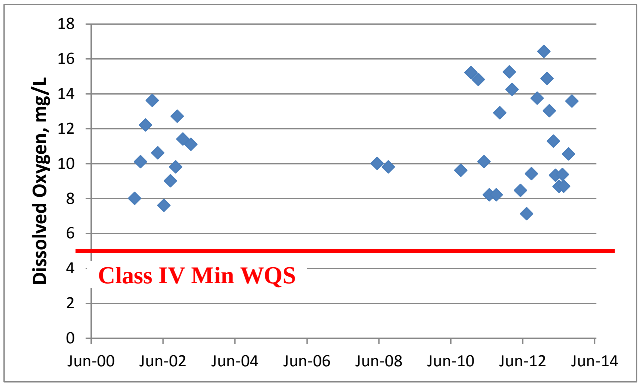

Figure 3-3. Field DO

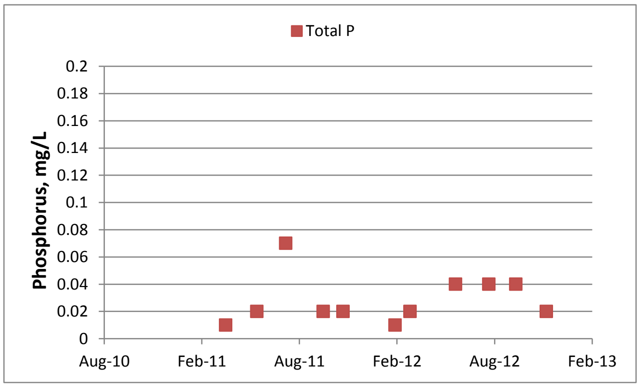

Figure 3-7. Phosphorus 2011-2012

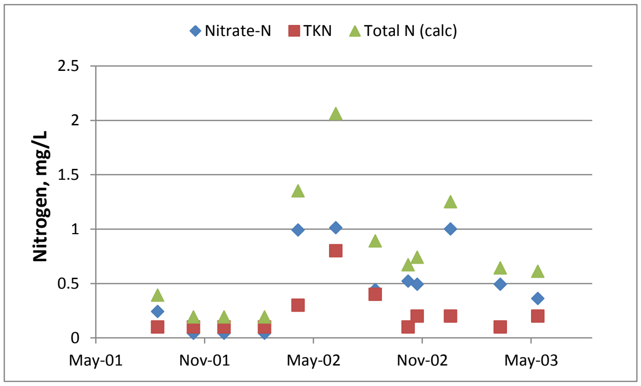

Figure 3-4. Nitrogen 2001-2003

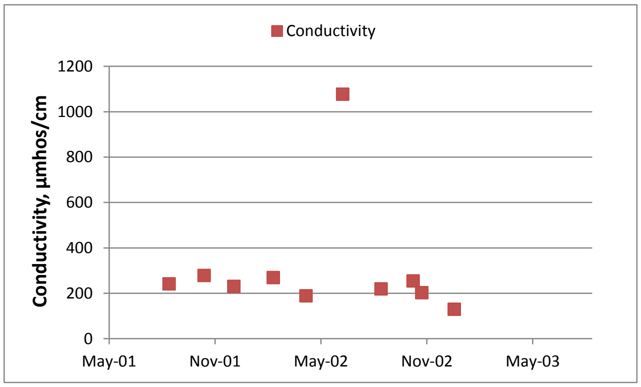

Figure 3-8. Conductivity 2001-2003

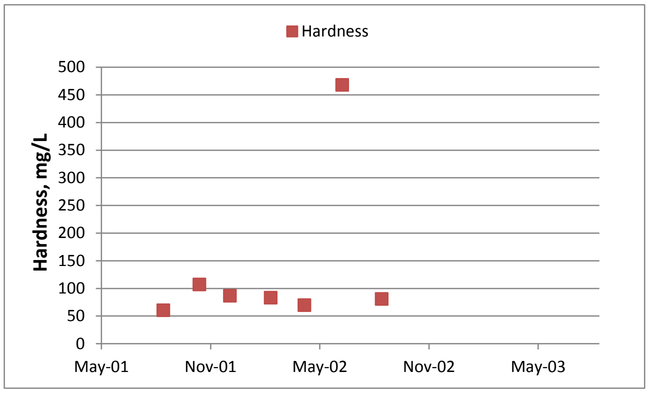

Figure 3-9. Hardness 2001-2003

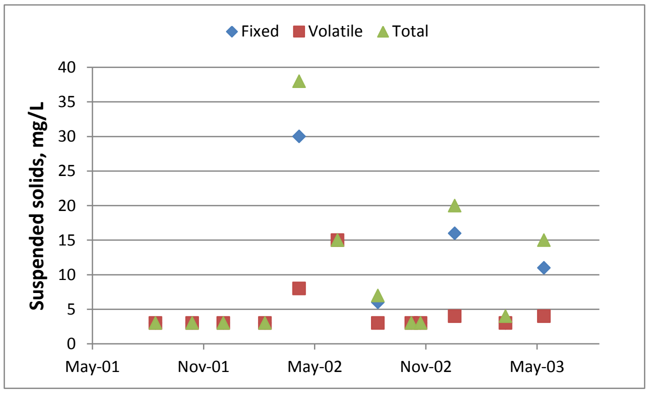

Figure 3-10. Suspended Solids 2001-2003

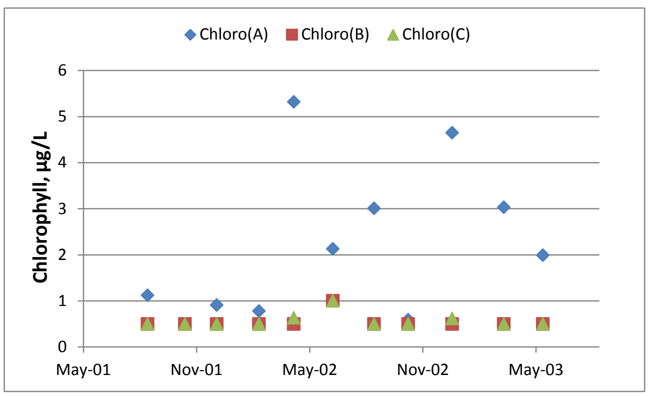

Figure 3-11. Chlorophyll 2001-2003

3.2. Friends of the Shenandoah River (FOSR) Ambient Data

- Ambient bi-weekly monitoring has been performed on the Happy Creek impaired segment at 5 locations throughout the watershed since January 2007, with various periods of record. Site FW09, near the outlet of Happy Creek, has been monitored through May 2009. Site FW10 on Sloan Creek has been monitored through September 2008. Site FW11, coincident with DEQ station 1BHPY002.67, has been monitored through the present. Site FW27, also near the outlet, was monitored through July 2008. Site FW29 on Leach Run, was monitored through May 2009.
- Plots of monthly ambient water quality monitoring sample data for all FOSR ambient monitoring stations on Happy Creek are shown in Figure 3-12 through Figure 3-18.
- Field physical parameters include temperature, pH, and DO. Chemical parameters include: ammonia; nitrate; orthophosphate-P; and turbidity.

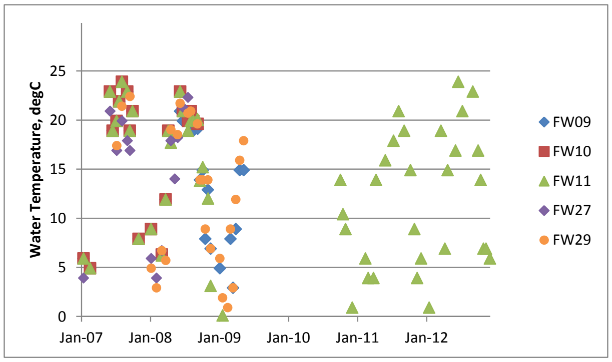

Figure 3-12. FOSR Water Temperature

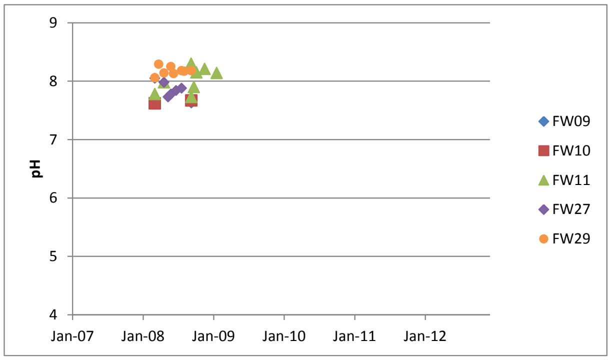

Figure 3-13. FOSR pH

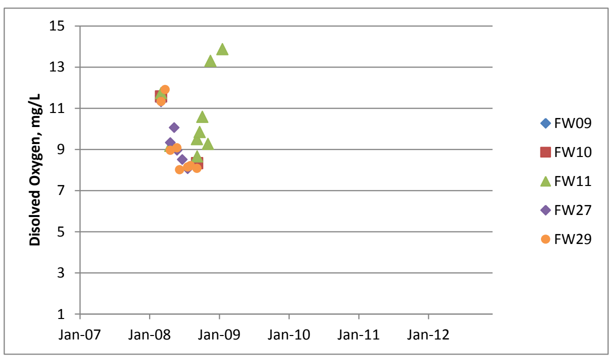

Figure 3-14. FOSR Dissolved Oxygen

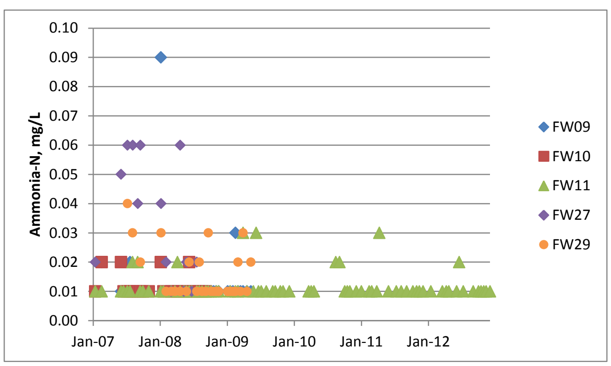

Figure 3-15. FOSR Ammonia

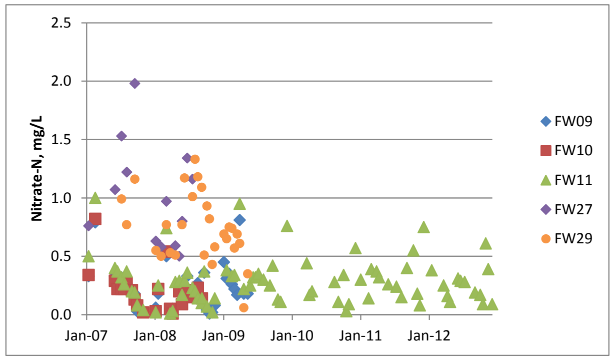

Figure 3-16. FOSR Nitrate-N

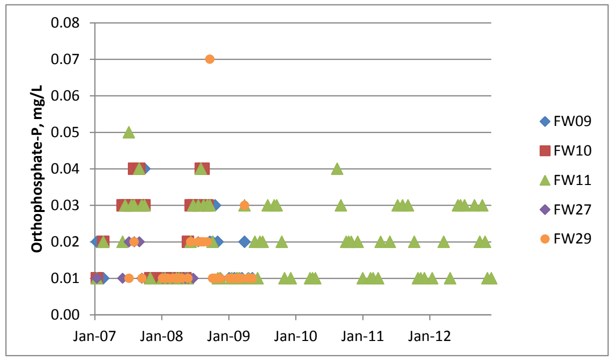

Figure 3-17. FOSR Orthophosphate-P

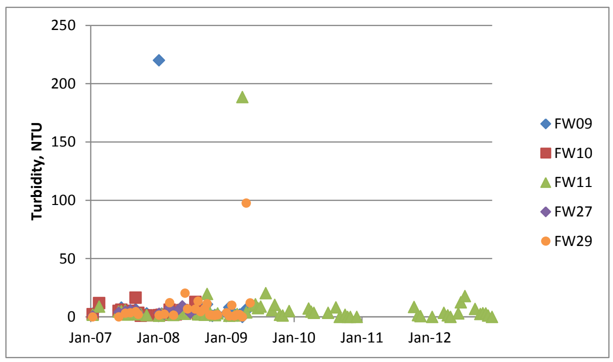

Figure 3-18. FOSR Turbidity

3.3. DEQ Stream Tests for Metals and Organic Compounds

- One sediment sample was collected for Happy Creek watershed at station 1BHPY002.67 on June 2, 2008 and analyzed by DEQ for a standard suite of metals.
- None of the tested substances exceeded any established consensus-based probable effects concentration (PEC) screening criteria, only copper barely exceeded its minimum threshold effects concentration (TEC) and most of the metals were not detected above their respective minimum detection limit (MDL) indicated by a Comment Code = "U", as shown in **Error! Reference source not found.**.

Table 3-4. Channel Bottom Sediment Monitoring and Screening Criteria for Metals

Parameter Name	Concentration (mg/kg)	Comment Code	Consensus-Based Criteria	
			TEC (mg/kg)	PEC (mg/kg)
ARSENIC IN BOTTOM DEPOSITS (MG/KG AS AS DRY WGT)	5	U	9.79	33
BERYLLIUM IN BOTTOM DEPOSITS(MG/KG AS BE DRY WGT)	5	U		
CADMIUM,TOTAL IN BOTTOM DEPOSITS (MG/KG,DRY WGT)	1	U	0.99	4.98
CHROMIUM,TOTAL IN BOTTOM DEPOSITS (MG/KG,DRY WGT)	26.6		43.4	111
COPPER IN BOTTOM DEPOSITS (MG/KG AS CU DRY WGT)	38.9		31.6	149
LEAD IN BOTTOM DEPOSITS (MG/KG AS PB DRY WGT)	19.3		35.8	128
MANGANESE IN BOTTOM DEPOSITS (MG/KG AS MN DRY WGT)	820			
NICKEL, TOTAL IN BOTTOM DEPOSITS (MG/KG,DRY WGT)	15.5		22.7	48.6
SILVER IN BOTTOM DEPOSITS (MG/KG AS AG DRY WGT)	1	U	0	0
ZINC IN BOTTOM DEPOSITS (MG/KG AS ZN DRY WGT)	98		121	459
ANTIMONY IN BOTTOM DEPOSITS (MG/KG AS SB DRY WGT)	5	U		
ALUMINUM IN BOTTOM DEPOSITS (MG/KG AS AL DRY WGT)	12100			
SELENIUM IN BOTTOM DEPOSITS (MG/KG AS SE DRY WGT)	1	U		
IRON IN BOTTOM DEPOSITS (MG/KG AS FE DRY WGT)	47900			
THALLIUM DRY WGTBOTMG/KG	5	U		
MERCURY,TOT. IN BOT. DEPOS. (MG/KG AS HG DRY WGT)	0.1	U	0.18	1.06

U = parameter analyzed, but not detected.
TEC = Threshold effects concentration; PEC = Probable effects concentration.

- One sample analyzed for dissolved metals was taken on the same day as the sediment metals sample. These results are shown in Table 3-5. No samples exceeded any of the applicable aquatic life, human health, or EPA nationally recommended freshwater criteria.
- Heavy metals such as mercury, chromium, cadmium, arsenic and lead in streams and rivers can damage aquatic insects at low concentrations. The metals tend to accumulate in the gills and muscles of aquatic organisms. Dissolved metals have been identified as important predictors of stream health. In the context of water quality criteria, dissolved metals are typically treated independently; however there is strong evidence that metals have a cumulative effect (Clements et al., 2000). The Cumulative Criterion Units (CCU) metals index accounts for this additive effect by standardizing each dissolved metal's concentration. The metals are summed together and the result is the CCU Metals Index score. When the CCU Metals Index is above 2, the cumulative effect is considered likely to harm aquatic life (Clements et al., 2000). The CCU score for this set of dissolved metals sample was 0.23, well below the threshold of concern.

Table 3-5. Dissolved Metals Monitoring and Screening Criteria

Parameter Name	Value	Comment Code	Aquatic Life Freshwater Criteria		Human Health Criteria	
			Acute (µg/L)	Chronic (µg/L)	Public Well Supplies	Other Surface Waters (µg/L)
CALCIUM, DISSOLVED (MG/L AS CA)	16.59					
CALCIUM, TOTAL (MG/L AS CA)	16.6					
MAGNESIUM, DISSOLVED (MG/L AS MG)	4.73					
MAGNESIUM, TOTAL (MG/L AS MG)	4.7					
ARSENIC, DISSOLVED (UG/L AS AS)	0.12		360	190		
ARSENIC, TOTAL (UG/L AS AS)	0.1	U				
BARIUM, DISSOLVED (UG/L AS BA)	13.65					
BARIUM, TOTAL (UG/L AS BA)	13.8					
BERYLLIUM, DISSOLVED (UG/L AS BE)	0.1	U				
CADMIUM, DISSOLVED (UG/L AS CD)	0.1	U	3.9	1.1		
CADMIUM, TOTAL (UG/L AS CD)	0.1	U				
CHROMIUM, DISSOLVED (UG/L AS CR)	0.38		1,700	210		
CHROMIUM, TOTAL (UG/L AS CR)	1.41					
COPPER, DISSOLVED (UG/L AS CU)	0.13		18	12	1,300	
COPPER, DISSOLVED (UG/L AS CU)	0.69					
COPPER, TOTAL (UG/L AS CU)	0.7					
IRON, TOTAL (UG/L AS FE)	165					
IRON, DISSOLVED (UG/L AS FE)	50	U				
LEAD, DISSOLVED (UG/L AS PB)	0.1	U	120	14	15	
LEAD, TOTAL (UG/L AS PB)	0.1	U				
MANGANESE, TOTAL (UG/L AS MN)	11.7					
MANGANESE, DISSOLVED (UG/L AS MN)	3.17					
THALLIUM, DISSOLVED (UG/L AS TL)	0.1	U				
THALLIUM, TOTAL (UG/L AS TL)	0.1	U				
NICKEL, DISSOLVED (UG/L AS NI)	0.12		180	20	610	4,600
NICKEL, TOTAL (UG/L AS NI)	0.19					
SILVER, DISSOLVED (UG/L AS AG)	0.1	U	4.1			
SILVER, TOTAL (UG/L AS AG)	0.1	U				
ZINC, DISSOLVED (UG/L AS ZN)	1	U	120	110	5,000	
ZINC, TOTAL (UG/L AS ZN)	1	U				
ANTIMONY, DISSOLVED (UG/L AS SB)	0.5	U				
ANTIMONY, TOTAL (UG/L AS SB)	0.5	U				
ALUMINUM, TOTAL (UG/L AS AL)	47.2					
ALUMINUM, DISSOLVED (UG/L AS AL)	2.97					
SELENIUM, DISSOLVED (UG/L AS SE)	0.5	U	20	5	170	11,000
SELENIUM, TOTAL (UG/L AS SE)	0.5	U				
MERCURY-TL,FILTERED WATER,ULTRATRACE METHOD UG/L	0.0015	U	2.4	0.012	0.052	0.053
MERCURY-TL,UNFILTERED WATER,ULTRATRACE METHOD UG/L	0.00173					
		U = parameter analyzed, but not detected.				

3.4. *Virginia DEQ – Other Relevant Monitoring or Reports*

- Relative Bed Stability (RBS) Analysis: Happy Creek has a relatively steep slope along its length resulting in efficient transport of sediment from upstream erosion, as shown in Table 3-6, although it has relatively high percentages of bedrock sand, and fines, the least usable substrates for good benthic macro-invertebrate habitat. A high percentage of fine sediment in streams would directly contribute to embeddedness, the filling of the interstitial spaces in the channel bottom. A Log Relative Bank Stability (LRBS) test is a type of siltation index. An LRBS score of negative one (-1) indicates that sediments ten times larger than the median are moving at bankfull, with a medium probability of impairment from sediment. LRBS scores < -1 are considered sub-optimal, while scores > -0.5 are considered optimal. The stream has a relatively high percentage of mean embeddedness according to this test. The LRBS scores upstream are in an optimal range, while the downstream site shows a greater impact from sediment, though not in the suboptimal range. The regional DEQ biologist stated that the assessment of the benthic impairment as being due to habitat problems is unclear.

Table 3-6. RBS Analysis Results

Station ID	Date	% Slope	% Bedrock	% Sand + Fines	Embeddedness	LRBS
1BHPY001.29	07/26/12	0.900	0%	31%	41.7	-0.816
1BHPY002.67	09/22/08	1.154	23%	33%	37.6	-0.218
1BHPY002.67	07/31/12	1.640	20%	32%	33.6	-0.225

3.5. *Virginia DEQ Permits in Happy Creek*

- There are no discharge permits for single-family homes in the watershed.
- There are no VPDES permits in the watershed.
- There is currently only one Industrial Stormwater General Permit in the watershed, as shown in Table 3-7.

Table 3-7. Mixed Concrete Discharge Permit

Permit No	Facility Name	Water Body	Receiving Stream
VAR050852	Zuckerman Metals, Inc.	VAV-B41R	Happy Creek

3.6. *DEQ Pollution Response Preparedness (PReP) Reports*

- 01/20/01: Gasoline spill enters storm sewer; 500 gal
- 11/16/06: Sewage overflow due to heavy rain; unknown volume (UNK)
- 08/15/08: Improper pond cleanout, sediment; UNK
- 09/22/08: Manhole overflowing; UNK
- 07/19/09: Sewage overflow; 15,000 gal
- 01/25/10: Sewage overflow at STP; 60,000 gal

3.7. *305(b)/303(d) Combined Report – Monitored Exceedances.*

- In the three biennial reports for 2008, 2010, and 2012 (VADEQ, 2008, 2010, and 2012), stations 1BHPY001.29 and 1BHPY002.67 on Happy Creek were listed with a biological impairment.

3.8. *VAHWQP Household Drinking Water Analyses*

- The Virginia Household Water Quality Program (VAHWQP) conducted Drinking Water clinics in Warren County in June 2012, where homeowners brought in well or spring water samples and/or tap water samples for water quality testing and analysis (Table 3-8). Some samples were from well water and some from tap water. While the samples may not be representative of the groundwater quality in the area, they do provide some information on general levels of physical and chemical parameters that may be impacted by groundwater.
- This program uses the EPA primary and secondary standards of the Safe Drinking Water Act, which are enforced for public systems as guidelines for private water supplies.

Table 3-8. Virginia Household Water Quality Program, County Drinking Water Clinic Results

2012 Warren County VAHWQP Drinking Water Clinic Results N = 44 samples				
Test	**EPA Standard**	**Average**	**Maximum Value**	**% Exceeding Standard**
Iron (mg/L)	0.3	0.237	2.804	18.2
Manganese (mg/L)	0.05	0.073	1.102	18.2
Hardness (mg/L)	180	90.7	373.5	22.7
Sulfate (mg/L)	250	101	1344	6.8
Fluoride (mg/L)	2.0/4.0	0.16	1.35	0.0
Total Dissolved Solids	500	273	941	11.4
pH	6.5 to 8.5	7.0	6.1 (min) 7.9 (max)	13.6 (<6.5) 0 (>8.5)
Sodium (mg/L)	20	43.26	248.2	31.8
Nitrate - N (mg/L)	10	1.799	17.338	2.3
Copper-First Draw (mg/L)	1.0/1.3	0.591	5.367	15.9
Copper-Flushed (mg/L)	1.0/1.3	0.065	1.417	2.3
Lead-First Draw (mg/L)	0.015	0.006	0.029	13.6
Lead-Flushed (mg/L)	0.015	0	0.002	0.0
Arsenic-First Draw (mg/L)	0.010	DL	0	0.0
Arsenic-Flushed (mg/L)	0.010	DL	0	0.0
Total Coliform Bacteria	ABSENT	91	1708	47.7
E. coli Bacteria	ABSENT	0	12	4.5

4.0 Analysis of Candidate Stressors for Happy Creek

The suspected source of the benthic impairment in Happy Creek was listed as generically as agricultural and non-point sources in the 2012 impaired waters fact sheet. The primary DEQ monitoring stations for biological monitoring are 1BHPF001.29 and 1BHPY002.67. The stressor may be something that either directly affected the benthic community or indirectly affected its habitat. The purpose of the stressor analysis is to look for a stressor that was present prior to the earliest bioassessment sampling in 2004, which caused Happy Creek's initial 2008 listing on the impaired waters list. VSCI ratings for Happy Creek suggest that its benthic community has some general stress throughout the system, but may have increased sources of stress between the upstream and downstream stations. While there are general upward trends in the VSCI scores at both sites, they both have experienced recent scores below 60.

A list of candidate stressors was developed and evaluated for Happy Creek in order to determine the pollutant(s) responsible for the benthic impairment. A potential stressor checklist was used to evaluate known relationships or conditions that may show associations between potential stressors and changes in the benthic community. Depending on the strength of available evidence, the potential stressors were "eliminated", considered as "possible" stressors, or recommended as the "most probable" stressor. Candidate stressors included ammonia, pH, hydrologic modifications, temperature, metals, toxic organic compounds, nutrients, organic matter, sediment, and ionic strength. The evaluation of each candidate stressor is discussed in the following sections.

4.1. Eliminated Stressors

4.1.1. Ammonia

High values of ammonia are toxic to many fish species and may affect the benthic community as well. Of the twelve samples collected by DEQ at station 1BHPY001.29 during 2001-2003, all were less than 0.04 mg/L, the minimum detection limit (MDL) of their analysis. FOSR recorded 40 samples collected at various points during the 2007-2012 period that were above their analysis MDL of 0.01 mg/L. Eleven of those 40 samples had corresponding pH and temperature data for evaluating chronic ammonia water quality standard (WQS) limits, although only 5 of those samples recorded ammonia concentrations greater than the MDL. All recorded ammonia concentrations greater than the MDL were 1-2 orders of magnitude less than their evaluated chronic WQS limits, which ranged from 1.07 to 2.25 mg/L. There were no upstream point sources and no reported fish kills that might point to ammonia as a possible stressor. Therefore ammonia was eliminated from further consideration as a stressor for Happy Creek.

4.1.2. pH

Benthic macroinvertebrates require a specific pH range of 6.0 to 9.0 to live and grow. Changes in pH may adversely affect the survival of benthic macroinvertebrates. Treated wastewater, mining discharge and urban runoff can potentially alter in-stream levels of pH. All pH samples reported by both DEQ and FOSR at various sites around Happy Creek all fall with the acceptable range of pH values and no in-stream pH exceedances have been reported at either DEQ monitoring station. Therefore, pH was eliminated from further consideration as a stressor.

4.1.3. Temperature

Elevated temperatures can stress benthic organisms and provide sub-optimal conditions for their survival. Happy Creek is classified as Class IV Mountainous Zones Waters with a maximum temperature standard of 31°C. No exceedances of the temperature standard were recorded at any of the DEQ or FOSR ambient monitoring stations. Therefore, no evidence supported temperature as a stressor, and it was eliminated.

4.1.4. Metals

Increased metals concentrations lead to low diversity and low total abundance of benthic organisms, with specific reduced abundance of metal-sensitive mayflies and increased abundance of metal-tolerant chironomids (Clements, 1994). Only one of the metals concentrations (copper) in one of the three channel bottom sediment sample exceeded any known consensus-based PECs and many were below MDL; none of the dissolved metals concentrations in the three samples exceeded either aquatic life or human health criteria; and the cumulative metals index was well below the threshold. None of the biological samples had low organism counts. Therefore, metals were eliminated from further consideration as a possible stressor.

4.1.5. Toxic Sediment Organic Compounds

Toxic substances by definition are not well tolerated by living organisms. The presence of toxics as a stressor in a watershed may be supported by very low numbers of any type of organisms, low organism diversity, exceedances of freshwater aquatic life criteria or consensus-based Probable Effect Concentrations (PEC) for metals or inorganic compounds, by low percentages of the shredder population, reports of fish kills, or by the presence of available sources. There have been no reports of fish kills and no samples were deficient in total numbers of organisms, although the shredder population was occasionally low at both DEQ benthic monitoring sites (6 out of 9 samples at 1BHPY001.29 and 3 out of 8 samples at 1BHPY002.67 had populations comprised of less than 2% shredders). Low shredder population could also be accounted for by poor habitat or excessive sediment. There were no sediment organic compounds tested in the three sediment samples, as there were no suspected sources of these compounds in the watershed. Therefore, toxic sediment organic compounds have been eliminated as a possible stressor.

4.1.6. Ionic Strength

Total dissolved solids (TDS) are the inorganic salts, organic matter and other dissolved materials in water. Elevated levels of TDS cause osmotic stress and alter the osmoregulatory functions of organisms (McCulloch et al., 1993). There were no TDS measurements reported at either DEQ monitoring station. The specific conductivity measurement at the station on Happy Creek had one sample in 2002 of

1,077 µmhos/cm, although most were less than 250 µmhos/cm, compared with the DEQ reference screening value of 500 µmhos/cm. Therefore, the evidence in support of ionic strength as a possible cause of the benthic impairment was considered insufficient, and it was eliminated as a stressor.

4.2. Possible Stressors

4.2.1. Nutrients

Excessive nutrient inputs can lead to increasing algal growth, eutrophication, and low dissolved oxygen concentrations that may adversely affect the survival of benthic macroinvertebrates. In particular, dissolved oxygen levels may become low during overnight hours due to plant respiration. Sources of nitrogen include groundwater, residential wastewater, atmospheric deposition, and agricultural activities. Nutrient-loving Chironimidae organisms were dominant in 4 out of 9 samples at 1BHPY001.29 and in 2 out of 8 samples at 1BHPY002.67. Each station had 2 samples where the two dominant species comprised more than 70% of the total population. Neither the dissolved N nor dissolved P concentrations were excessively high, although in the 2001-2003 period average total P concentrations were less than optimal, but were in the optimal range (< 0.3 mg/L) when monitored in 2011-2012. Total N concentrations all appear to be in the optimal range (< 1 mg/L). Although the populations were occasionally dominated by Chironomidae, there is a fair diversity of organisms at the downstream station, with greater diversity along with a greater number of sensitive species at the upstream station. Therefore, nutrients do not appear to be the major impact on the biological community in Happy Creek, but were considered a possible stressor.

4.2.2. Organic Matter

Excessive organic matter can lead to low in-stream dissolved oxygen concentrations, which may adversely affect the survival and growth of benthic macroinvertebrates. Potential sources of organic matter in Happy Creek include household wastewater discharges, sewage overflows and spills, malfunctioning septic systems, livestock, and runoff from impervious areas. Organic enrichment is supported by the types of abundant benthic organisms found in many of the samples – Hydropsychidae and Chironomidae – typical of organic-enriched sites. High metric values of the Modified Family Biotic Index (MFBI) metric (>5.50) occurred in 6 of the 9 samples at 1BHPY001.29 and in 0 of the 8 samples at 1BHPY002.67, while low values of the shredder/filterer-collector ratio (< 0.5) occurred in all 9 samples at 1BHPY001.29 and in 6 of the 8 samples at 1BHPY002.67. Additionally two very pollutant-tolerant species were dominant in 7 of the 9 samples at station 1BHPY001.29, including one sample with a dominant population of Tubificidae, an organism indicative of raw sewage. Organic matter, therefore, was considered a possible stressor, although not supported by usually corresponding elevated levels of nutrients, or low DO concentrations.

4.2.3. Hydrologic Modifications

Hydrologic modifications can cause shifts in the supply of water, sediment, food supply, habitat, and the changed environment can support pollutants from one part of the watershed to another, thereby causing changes in the types of biological communities. Happy Creek runs through the middle of the town of Front Royal and is intersected by 21 road crossings and two railroad crossings that constrict channel movement and contribute to scouring downstream of these structures. There are also several in-stream impoundments along the Sloan Creek tributary and in the upper reaches of Happy Creek which will affect hydrology, together with an increased degree of impervious surfaces in the urban areas. Therefore, hydrologic modification may be a possible stressor.

4.3. Most Probable Stressors

The most probable stressor contributing to the impairment of the benthic community in Happy Creek is considered to be sediment based on the following summary of available evidence.

4.3.1. Sediment

Excessive sedimentation can impair benthic communities through loss of habitat. Excess sediment can fill the pores in gravel and cobble substrate, eliminating macroinvertebrate habitat. Potential sources of sediment include residential runoff, forestry and agricultural runoffs, livestock access to streams, construction sites, and in-stream disturbances. Habitat metric scores for riparian vegetative protection are poor in all samples at the downstream 1BHPY001.29 site and in 5 of the 8 samples at the upstream site. Anecdotal evidence points to crowds of fishermen competing for fishing spots the mornings after the creek is stocked, possibly contributing to the poor riparian vegetation in some spots. Bank stability scores were low in half of the samples at the upstream 1BHPY002.67 site. Although, as is typically the case, there are no large concentrations of total suspended solids (TSS) or turbidity to corroborate high sediment as most samples are taken during ambient conditions, and most sediment is contributed during storm events. The LRBS siltation index score was -0.82 at the downstream site, which indicates moderately excessive sediment from anthropogenic sources in the stream bottom; while the upstream site whose impairment is less severe has had two LRBS scores in 2008 and 2012 in the range of -0.22 to -0.23, indicating minimal influence from anthropogenic sources. Sediment is supported as the possible stressor based on the consistently poor riparian vegetation and bank stability habitat metrics and the less than optimal LRBS score at the downstream site. Although the upstream site has an optimal LRBS score, it also has a minor impairment, and will probably not give as strong a signal as the more impaired downstream sight.

4.4. Conclusions

The Happy Creek (VAC-B41R_HPY01A00 and VAC-B41R_HPY02A00) stream segments are impaired for its aquatic life use. Happy Creek is impacted by a combination of agricultural and urban land uses. Sediment was selected as the most probable stressor based on poor riparian vegetation habitat metrics at both sites, along with poor bank stability metrics at the upstream site, and poor channel alteration metric scores and moderate impacts on the LRBS siltation metric shown at the downstream site.

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